

Dynamics of magnetized spherical accretion flows

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Abstract. Transonic accretion flow with self-consistent treatment of the magnetic field is presented. My website <http://www.cfa.harvard.edu/~rshcherb/>.

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INTRODUCTION

The averaged quantities can be obtained in two different ways in magnetohydrodynamics. The first way is to solve 3D MHD equations and then average the results. The second way is to solve some system of equations on averages. Combination of numerical simulations and averaged theory brings phenomenology that can describe observations or experimental data.

The problem of spherically symmetric accretion takes its origin from Bondi's work [2]. He presented idealized hydrodynamic solution with accretion rate \dot{M}_B . However, magnetic field \vec{B} always exists in the real systems. Even small seed \vec{B} amplifies in spherical infall and becomes dynamically important [9].

Magnetic field inhibits accretion [9]. None of many theories has reasonably calculated the magnetic field evolution and how it influences dynamics. These theories have some common pitfalls. First of all, the direction of magnetic field is usually defined. Secondly, the magnetic field strength is prescribed by thermal equipartition assumption. In third, dynamical effect of magnetic field is calculated with conventional magnetic energy and pressure. All these inaccuracies can be eliminated.

In Section 2 I develop a model that abandons equipartition prescription, calculates the magnetic field direction and strength and employs the correct equations of magnetized fluid dynamics. In Section 3 I show this accretion pattern to be in qualitative agreement with Sgr A* spectrum models. I discuss my assumptions in Section 4.

ANALYTICAL METHOD

Reasonable turbulence evolution model is the key difference of my method. I build an averaged turbulence theory that corresponds to numerical simulations. I start with the model of isotropic turbulence that is consistent with simulations of collisional MHD in three regimes. Those regimes are decaying hydrodynamic turbulence, decaying MHD turbulence and dynamo action. I introduce effective isotropization of magnetic field in

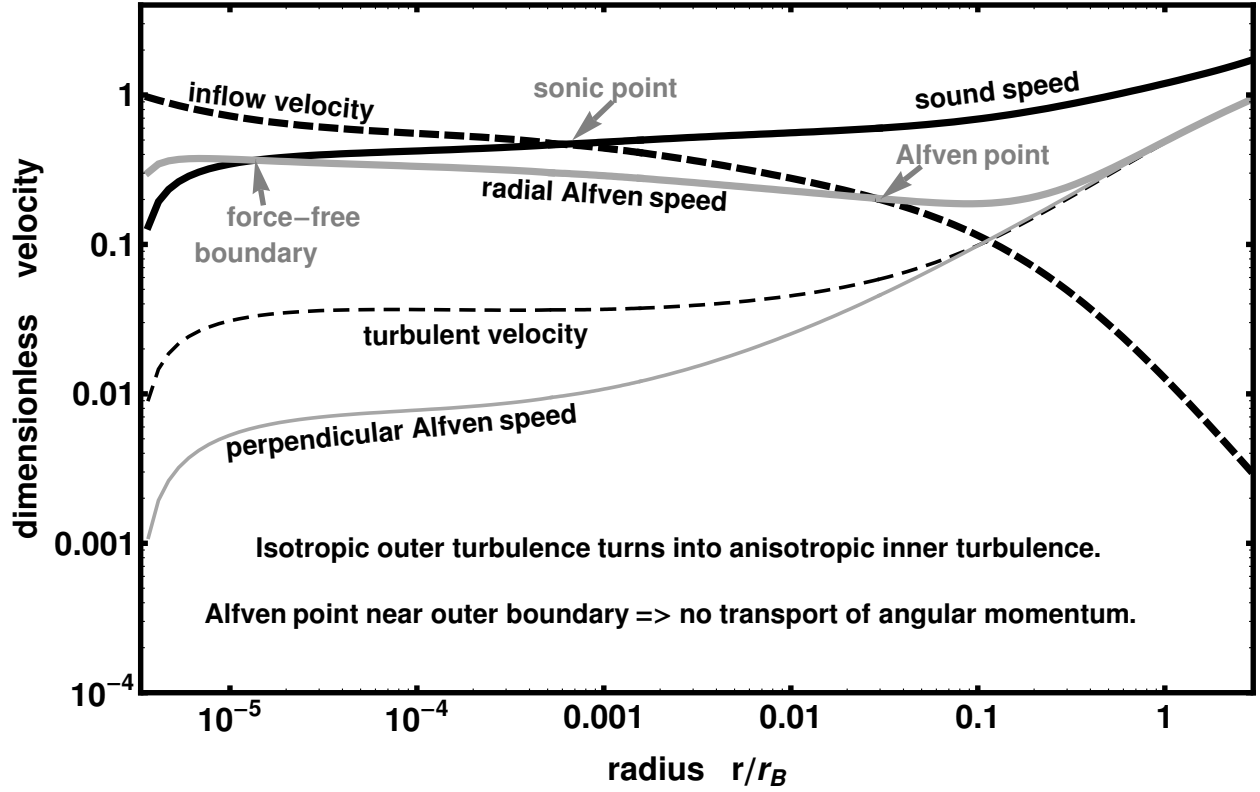


FIGURE 1. Normalized to Keplerian speed characteristic velocities of magnetized flow. Horizontal lines correspond to self-similar solution $v \sim r^{-1/2}$.

3D model. Isotropization is taken to have a timescale of the order of dissipation timescale that is a fraction $\gamma \sim 1$ of the Alfvén wave crossing time $\tau_{\text{diss}} = \gamma r / v_A$.

Common misconception exists about the dynamical influence of magnetic field. Neither magnetic energy nor magnetic pressure can represent \vec{B} in dynamics. Correct averaged Euler and energy equations were derived in [7] for radial magnetic field. Magnetic force $\vec{F}_M = [\vec{j} \times \vec{B}]$ can be averaged over the solid angle with proper combination of $\vec{\nabla} \cdot \vec{B} = 0$. I extend the derivation to random magnetic field without preferred direction. Dynamical effect of magnetic helicity [1] is also investigated. I neglect radiative and mechanical transport processes.

The derived set of equations requires some modifications and boundary conditions to be applicable to the real astrophysical systems. I add external energy input to turbulence to balance dissipative processes in the outer flow. The outer turbulence is taken to be isotropic and has magnetization $\sigma \sim 1$. Transonic smooth solution is chosen as possessing the highest accretion rate as in [2].

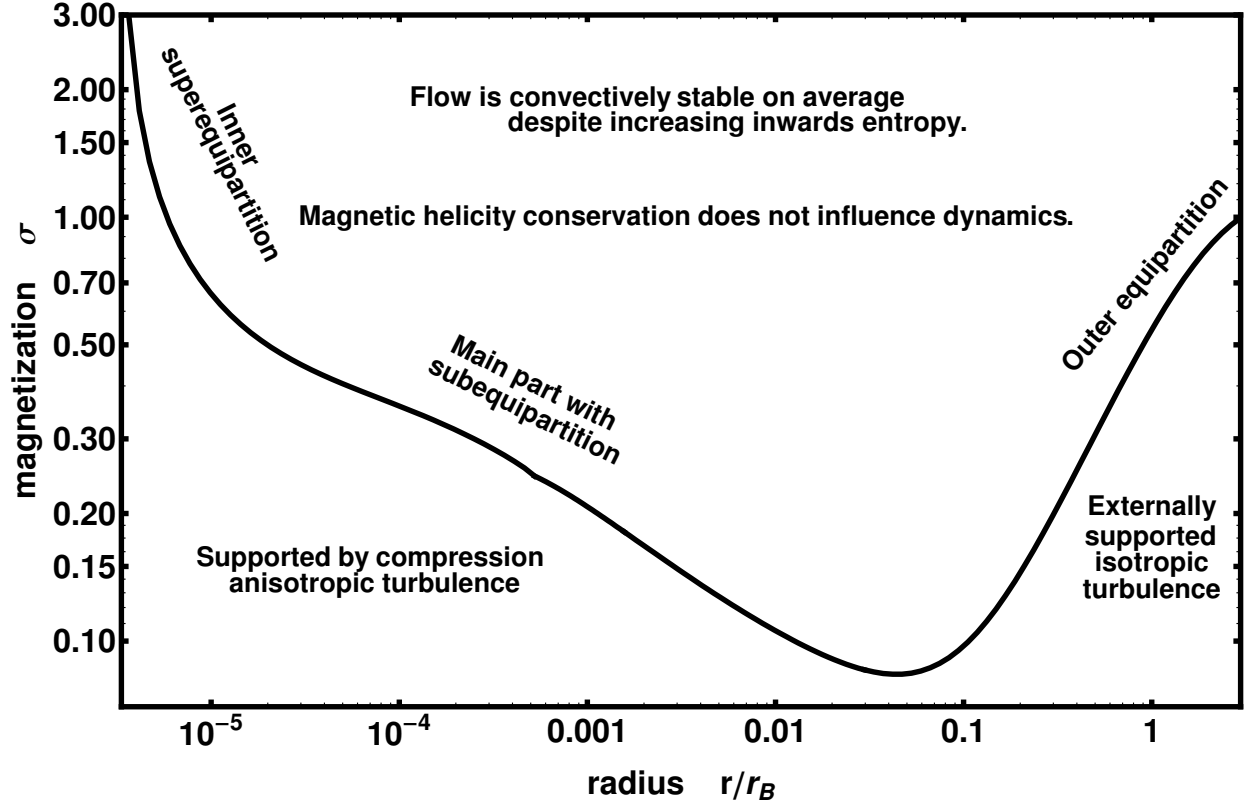


FIGURE 2. Plot of magnetization $\sigma = (E_M + E_K)/E_{Th}$ with radius.

RESULTS & APPLICATION TO SGR A*

The results of my calculations confirm some known facts about spherical magnetized accretion, agree with the results of numerical simulations and have some previously unidentified features.

Initially isotropic magnetic field exhibits strong anisotropy with larger radial field B_r . Perpendicular magnetic field $B_\perp \ll B_r$ is dynamically unimportant in the inner accretion region Fig1. Because magnetic field dissipates, infall onto the black hole can proceed [9].

Turbulence is supported by external driving in the outer flow regions, but internal driving due to freezing-in amplification takes over in the inner flow Fig2. Magnetization of the flow increases in the inner region with decreasing radius consistently with simulations [3]. Density profile appears to be $\rho \sim r^{-1.25}$ that is different from traditional ADAF scaling $\rho \sim r^{-1.5}$ [6]. Thus the idea of self-similar behavior is not supported.

Compared to non-magnetized accretion, infall rate is 2-5 times smaller depending on outer magnetization. In turn, gas density is 2-5 times smaller in the region close to the black hole, where synchrotron radiation emerges [6]. Sgr A* produces relatively weak synchrotron [6]. So, either gas density n or electron temperature T_e or magnetic field B are small in the inner flow or combination of factors works. Thus low gas density in magnetized model is in qualitative agreement with the results of modelling the spectrum.

Flow is convectively stable on average in the model of moving blobs, where dissipation heat is released homogeneously in volume. Moving blobs are in radial and perpendicular pressure equilibriums. They are governed by the same equations as the medium.

DISCUSSION & CONCLUSION

The presented accretion study self-consistently treats turbulence in the averaged model. This model introduces many weak assumptions instead of few strong ones.

I take dissipation rate to be that of collisional MHD simulations. But flow in question is rather in collisionless regime. Observations of collisionless flares in solar corona [5] gives dissipation rate 20 times smaller than in collisional simulations [1]. However, flares in solar corona may represent a large-scale reconnection event rather than developed turbulence. It is unclear which dissipation rate is more realistic for accretion.

Magnetic field presents another caveat. Magnetic field lines should close, or $\vec{\nabla} \cdot \vec{B} = 0$ should hold. Radial field is much larger than perpendicular in the inner region. Therefore, characteristic radial scale of the flow is much larger than perpendicular. If radial turbulence scale is larger than radius, freezing-in condition does not hold anymore. Matter can freely slip along radial field lines into the black hole. If matter slips already at the sonic point, the accretion rate should be higher than calculated.

Some other assumptions are more likely to be valid. Diffusion should be weak because of high Mach number that approaches unity at large radius. Magnetic helicity was found to play very small dynamical role. Only when the initial turbulence is highly helical, magnetic helicity conservation may lead to smaller accretion rate. Neglect of radiative cooling is justified a posteriori. Line cooling time is about 20 times larger than inflow time from outer boundary.

The study is the extension of basic theory, but realistic analytical models should include more physics. The work is underway.

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